EXPLORESPACE TECH

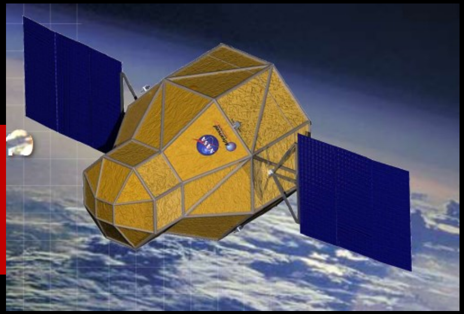
TECHNOLOGY DRIVES EXPLORATION

GO: Cryogenic Fluid Management
NASA Space Technology Mission Directorate

STMD welcomes feedback on this presentation. Please visit https://techport.nasa.gov/framework/feedback if you have any questions or comments regarding this presentation.

GO: Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications.

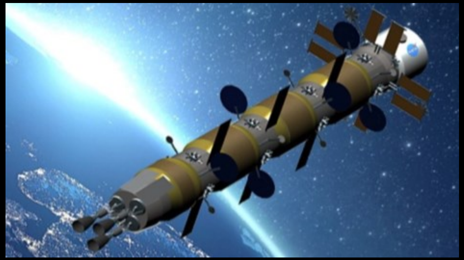
Developing technologies for near zero boil off storage, high efficiency chill-down and liquification, propellant transfer, and instrumentation to support Mars transportation and surface ISRU architectures.

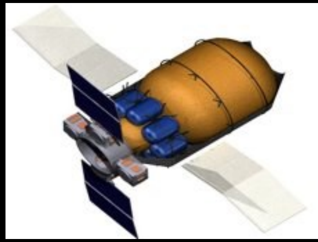


STORAGE

- LOX, LCH4, LH2
- Near Zero Boil-off – Architecture / mission dependent

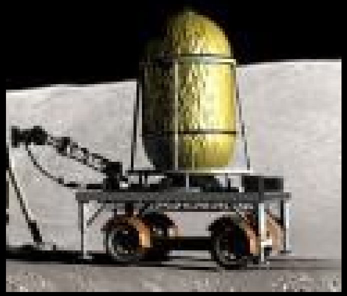
- **Critical Technologies**
  - Active Thermal Control
  - High Performance Insulation
  - Structural Heat Rejection/Intercept
  - Pressure Control
  - Operations
  - Near Zero Boil-off
  - Structural Multilayer Insulation
  - Low conductance structures
  - High Efficiency High Capacity 20 K and 90 K Cryocoolers
  - Destratification
  - Unsettled Mass Gauging
  - Thermal Control Coatings





LIQUEFACTION

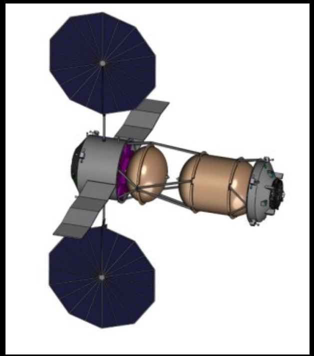
- H2, O2, CH4
- Initial system performance: 2 kg/hr of O2 and 0.3 kg/hr of H2
- Soft Vacuum insulation: 1.5 W/m2 at 250 K



TRANSFER

- Propellant losses ≤1% during transfer
- <1% residual in supply tank

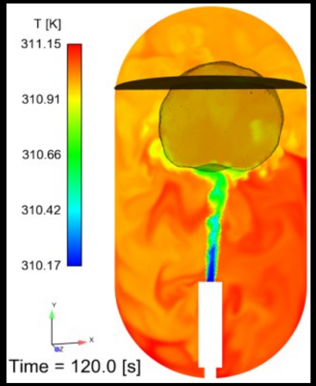
- **Critical Technologies**
  - Component Technologies
  - Operations
  - High efficiency chill down of tank and lines
  - Automated Cryo-Couplers
  - Low-leakage valves/actuators
  - Flow Meters
  - Efficient Liquid Acquisition Devices
  - Transfer pump



NON-PRIMARY PROPULSION

- Integrated RCS
- Fuel Cells
- ECLSS

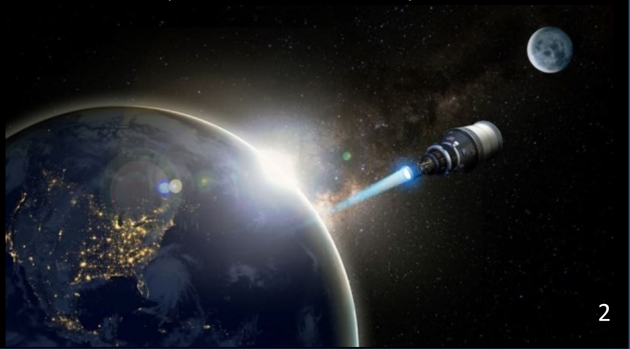
- Application Specific CFM Capabilities
- Uses components and processes from other categories



INTEGRATED OPERATIONS / PREDICTIVE PERFORMANCE

- Advanced instrumentation, data acquisition and signal processing
- Integrated Demonstration
- Accurate and robust a priori microgravity thermal-fluid predictions
  - Validated foundational physics in High Fidelity tools
  - High-to-Low Fidelity Model Integration

- Integrated System Performance Analysis
  - Low predictive uncertainty



CFM State of the Art

CFM capabilities must address the operational implementation and use of the technologies in a system, and the technical design of the CFM system. Many of the components required to close the gaps are the same but have diverging requirements or implementation strategies that change how the technology is used.

STORAGE

- Extensive experience in ground demonstration
- Longest H_2 cryogenic propulsion storage system has performed storage operations in space is 9 hrs
- Performed 4.5 Month CH4 subscale storage on RRM3

KEY Design Details

- Tank pressure regulation
- Methods of venting
- Structural heat load
- Total heat input over time
- Active cooling – **1W lift @ 20 K; 20W lift @ 90 K**

LIQUEFACTION

- **Ground based demonstration** and analytical performance model validation of **LN2**

KEY Design Details

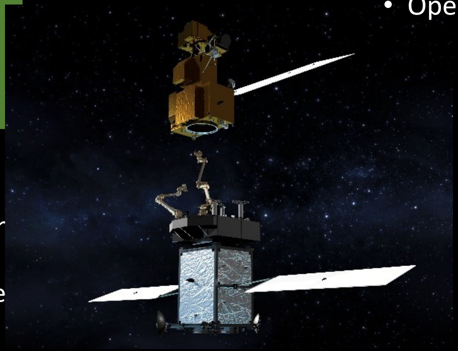
- Condensation, fluid physics, fluid purity
- Active cooling integration
- High performance insulation in appropriate environment

TRANSFER

- **Component brassboard** hardware **ground testing only**

Key Design Details

- Pump or pressure driven transfer
- High efficiency chill down of tank and lir
- Active cooling
- Low-leakage valves/actuators, leak dete
- Phase separation/Liquid acquisition

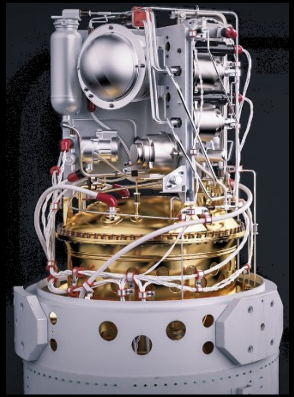


NON-PRIMARY PROPULSION

- **Ground based testing** of Integrated RCS in thermal vacuum

KEY Design Details

- Application specific technologies and operational processes

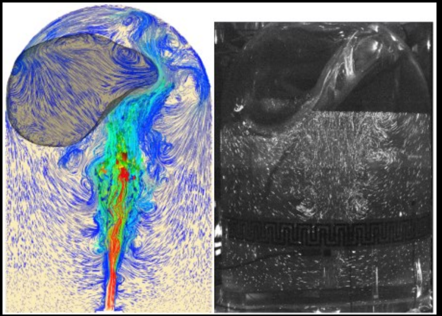


INTEGRATED OPERATIONS / PREDICTIVE PERFORMANCE

- Fluid property knowledge gaps
- Instrumentation
- Model development and validation for both high and low fidelity applications

KEY Design Details

- Zero-G Mass Gauging
- Operational and predictive fluid dynamics and thermodynamics



CFM Critical Technologies Current Investments

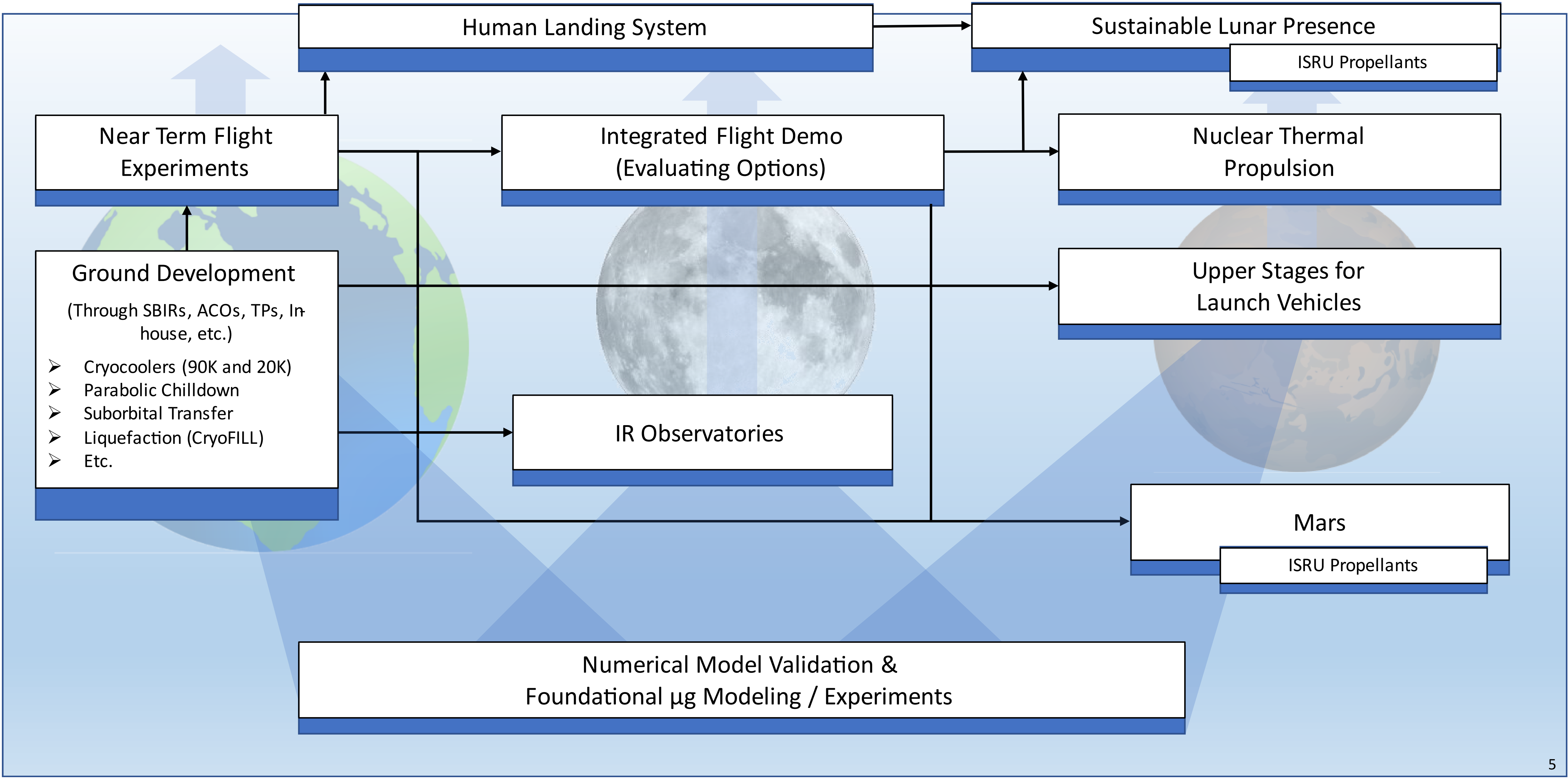
CFM Critical Technology Gaps	Cross Cutting or Fluid Specific	Current TRL	Gap Addressed**
Low Conductivity Structures	Cross Cutting	6	Tipping Point (TP)
High Vacuum Multilayer Insulation	Cross Cutting	6	FY20 TP
Sun Shields (deployment mechanism)	Cross Cutting	5	JWST / TP
Tube-On-Shield BAC	Cross Cutting	5	TP, In-house
Valves, Actuators & Components	Cross Cutting	4-5	TP, In-house
Vapor Cooling	Fluid Specific	6	TP, In-house
Propellant Densification	Fluid Specific	5	TP, In-house
Unsettled Liquid Mass Gauging, multiple methods	Cross Cutting	4-7	TP, ECI, FO, In-house
Sub-surface Helium Pressurization in Micro-g	Cross Cutting	5	ZBOT / TP
Line Chilldown (MPS, iRCS, Transfer)	Cross Cutting	5	TP
Pump Based Mixing	Cross Cutting	5	ZBOT / TP
Thermodynamic Vent System	Cross Cutting	5	TP
Tube-On-Tank BAC	Cross Cutting	5	In-house
Liquid Acquisition Devices	Fluid Specific	5	TP
Advanced External Insulation	Cross Cutting	4	Paragon / CELSIUS
Automated Cryo-Couplers	Cross Cutting	4	TPs, HLS, ECI
Cryogenic Thermal Coating	Cross Cutting	4	TP, In-house
High Capacity, High Efficiency Cryocoolers 90K	Cross Cutting	4	In-house
Soft Vacuum Insulation	Cross Cutting	3	MAV (MSR)
Structural Heat Load Reduction	Cross Cutting	3	CIF
Propellant Tank Chilldown	Cross Cutting	4	FY20 TP
Transfer Operations	Cross Cutting	4	FY20 TP
High Capacity, High Efficiency Cryocoolers 20K	Fluid Specific	4	In-house
Liquefaction Operations (MAV & ISRU)	Fluid Specific	4	TP / In-house
Para to Ortho Cooling	Fluid Specific	4	TP
Cryogenic Flow Meter	Cross Cutting	4	TP
Autogenous Pressurization in Micro-g*	Fluid Specific	4	ZBOT / TP
CFM Modeling Capability	Cross Cutting	2-9	ZBOT, In-house, STRG, FO

- NASAs CFM Portfolio has contributed extensively to bringing CFM critical technologies to TRL 4-6
- Significant SBIR program leverage
- Nearly all are receiving active investments
- Recent focus has been on advancing the CFM component and subsystem technologies beyond the mid-range TRL level and developing integrated flight demonstrations to support NASA's future missions
- Future focus will be closing out the current lower TRL investments and development of the near-term flight demonstrations
- HLS Leverage for multiple components
- Industry leverage (e.g. Lockheed Martin, Blue Origin, SpaceX, Eta Space, etc.)
- SMD ZBOT demonstrations and model validation
- High to low fidelity model development and validation to predict future mission capabilities

* Note: Traditional settled pressurization methods TRL 9

** Note: Addressing the gap does not in all cases equate to gap closure; some gaps are fluid or architecture specific; the goal is to develop high-fidelity models to support mission designs.

Long Term CFM Strategy and End User Applications



CFM Investment Approach

Ground Development (Current CFM Projects)

- Multiple ground-based component and subassembly projects addressing the CFM critical technologies
- Many of these lower-level capability demonstrations are advanced in technology readiness through the Tipping Point integrated system demonstrations
- CFM technologies supporting ISRU architectures do not require micro-g and TRL can be advanced to 6/7 in ground testing.

Near-Term Demonstrations (FY20 Tipping Points)

- STMD is sponsoring a significant Tipping point award to incentivize Industry to fly CFM experiments that will combine many of these CFM technologies to develop and raise the TRL level of storage and transfer
- Four flight demonstrations have been selected for award and are expected to fly by 2025
- Significant technology maturation is stalled in wait of integrated system and/or relevant environment testing

Large Integrated Flight Demonstration

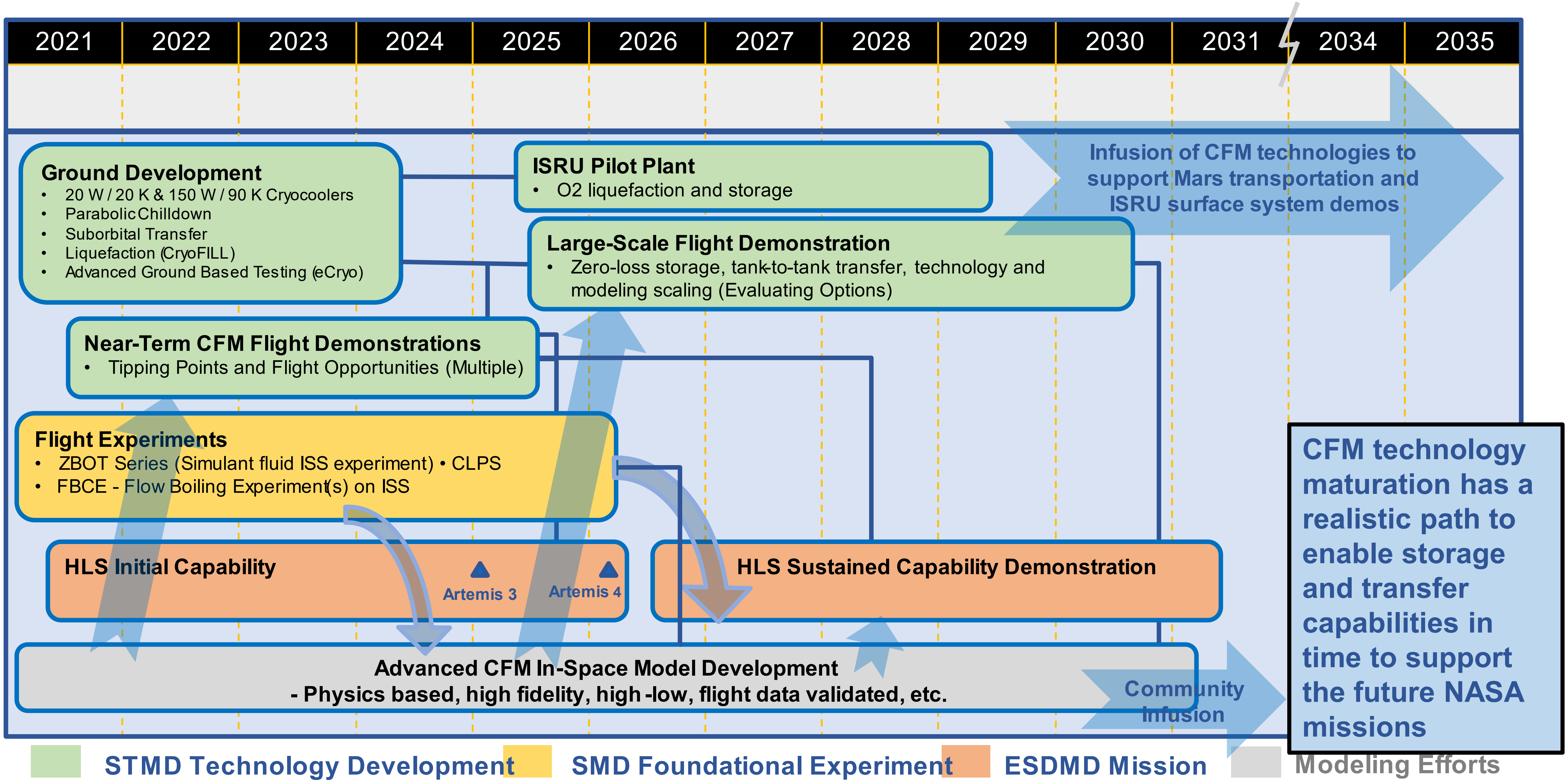
- Evaluating Options

Leverage the Human Landing System (HLS) Development and Demonstration

- Utilizing the data and performance gathered during the Near-Term Demonstrations and other mature enabling and enhancing technologies, the CFM individual systems will be demonstrated in a scalable flight experiment directly addressing the performance needs of CFM stakeholders.
- Post flight, CFM technologies will be ready to support NTP and other deep space Cryo stage missions

Operations Optimization

CFM Notional Near-Term Roadmap



Notional Timeline

Capability Gap Performance Goals

Storage

- Lunar Human Return/Exploration: Cryogenic propellant storage with near zero boil-off dependent on architecture and mission duration; LOx, LCH_4, LH_2
- Long Term Lunar/Mars/ISRU: Zero Boil-off (net head load of less than zero); LOx, LCH_4, LH_2; includes thermal insulation and structural interfaces limiting heat leak into tanks

Transfer

- Propellant losses of 1% (TBR) or less during transfer activity
- <1% (TBR) residual in supply tank

Liquefaction

- Integrated system performance of 2 kg/hr of O_2 and 0.3 kg/hr of H_2
- Fluids to demonstrate: LOx, LCH_4, LH_2

Predictive Model Validation

- Demonstrate that the relative difference between CFD or nodal model results and test data is less than 15% (TBR) for pressure time histories and less than 30% (TBR) for (fluid and/or wall) temperature time histories
  - Sufficient for acceptable performance margin (TBD) of operational systems

Acronyms and Abbreviations

- ACO: Announcement of Collaboration Opportunity
- BAC: Broad Area Cooling
- CELSIUS: Cryogenic Encapsulating Launch Shroud and Insulated Upper Stage
- CFM: Cryogenic Fluid Management
- CLPS: Commercial Lunar Payload Services
- Cryo: Cryogenic
- ECI: Early Career Initiative
- ECLSS: Environmental Control and Life Support System
- FBCE: Flow Boiling and Condensation Experiment
- FO: Flight Opportunities
- FY: Fiscal Year
- HEOMD: Human Exploration and Operations Mission Directorate
- HLS: Human Landing System
- IR: Infrared
- IRCS: Integrated Reaction Control System
- ISRU: In-Situ Resource Utilization
- ISS: International Space Station
- JWST: James Webb Space Telescope
- LCH_4: Liquid Methane
- LH_2: Liquid Hydrogen
- LOx: Liquid Oxygen
- MAV: Mars Ascent Vehicle
- Micro-g: Micro gravity
- MSR: Mars Sample Return
- NASA: National Aeronautics and Space Administration
- NTP: Nuclear Thermal Propulsion
- RCS: Reaction Control System
- RRM3: Robotic Refueling Mission 3
- SBIR: Small Business Innovation Research
- SMD: Science Mission Directorate
- STMD: Space Technology Mission Directorate
- STRG: Space Technology Research Grants
- TBD: To Be Determined
- TBR: To Be Resolved
- TP: Tipping Point
- TRL: Technology Readiness Level
- ZBOT: Zero Boil-Off Tank
- Zero-g: Zero gravity